Community Building of the Global Ocean Modeling Component of EPIC

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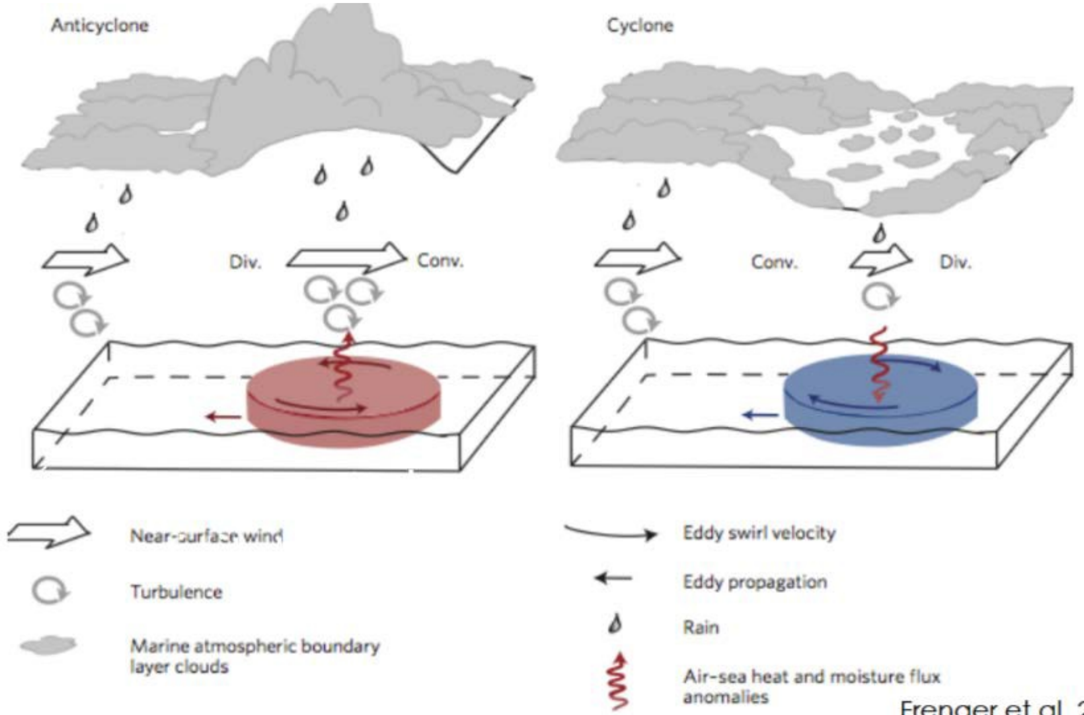
Earth System Modeling implies an ocean component

Current Unified Forecast System (UFS) applications

	Atm	Land	Ocean	Sea Ice	Aerosol	Ionosphere	Storm Surge	Wave
Weather	●	●	?					
S2S	●	●	●	●	●			
Hurricane	●	●	●					
Short-Range Weather	●	●						
Space Weather	●	●				●		
Marine and Cryosphere			●	●				
Coastal							●	●
Air Quality	●	●			●			

Ocean’s impact on atmosphere and vice-versa

- Proven on S2S time scales – coupled ocean-atmosphere configuration => CFSv2 (coarse ocean resolution ~0.25° to 0.5°)
- Proven for hurricanes
- But its is also important on weather scales (with fine ocean resolution)
  - Wind stress is strongly dependent on ocean current and SST, especially at fine resolution (i.e. eddy resolving, ~1/10°)
  - Imprints of surface ocean currents on the surface wind in satellite observations and atmosphere−ocean coupled models.
  - Oceanic mesoscale eddies are losing kinetic energy to the atmosphere and conversely the atmosphere is rectified in the direction of surface oceanic currents, partly compensating the energy loss of the surface currents.
- The community is moving away from ocean-only prediction systems



Frenger et al. 2013

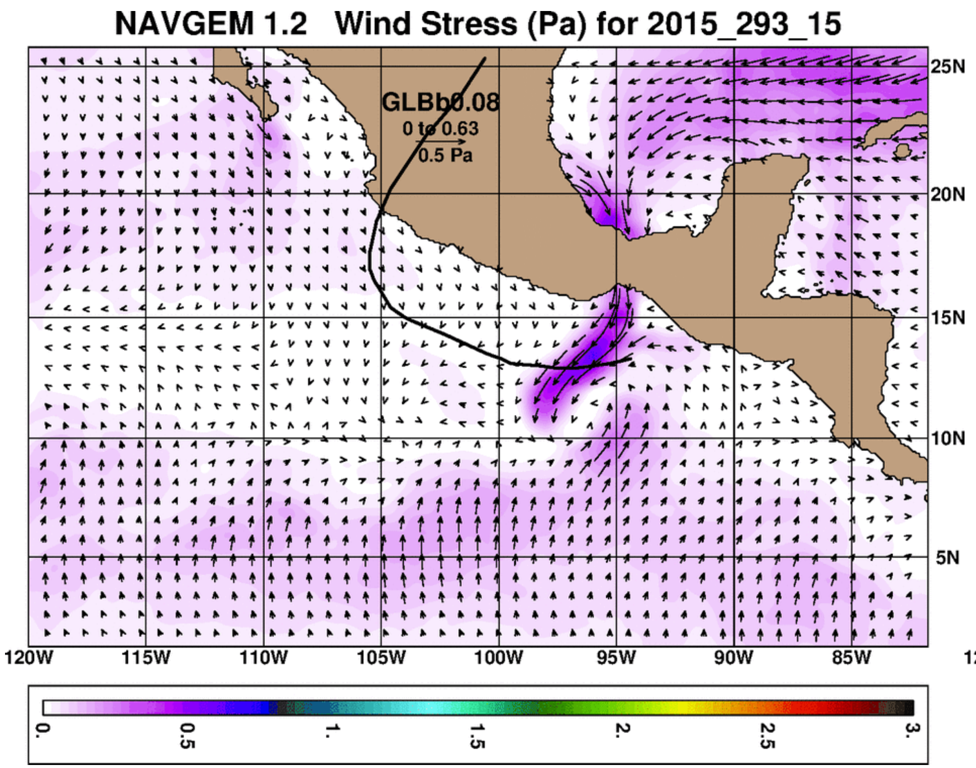
Seamless prediction from day 1 to S2S

- ECMWF Integrated Forecasting System (IFS) with NEMO 1/4° ocean model
  - "Using interactive ocean and sea ice components in ECMWF's Integrated Forecasting System (IFS) can significantly improve sea-surface temperature predictions in Europe and, as a result, predictions of near-surface air temperature" (Mogensen et al., 2018)
- UKMET
- Navy ESPC with HYCOM 1/12° and 1/25° ocean models

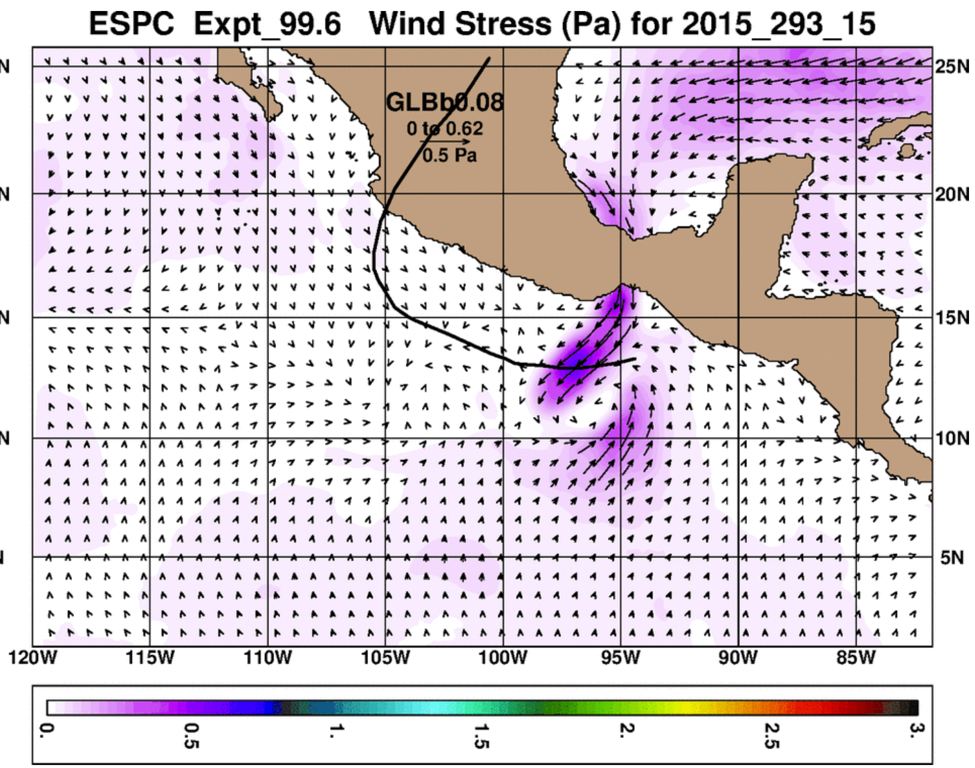
Forecast	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3[3]
Deterministic short term	0-16 days, Daily	T681L60 (19 km) 60 levels	1/25° (4.5 km) 41 layers	1/25° (4.5 km)	1/8° (14 km)
Probabilistic long term	0-45 days Configuration TBD*	T359L60 (37 km) 60 levels	1/12° (9 km) 41 layers	1/12° (9 km)	1/4° (28 km)

Patricia's Predicted Wind Stress

Operational NAVGEM Forecasts



ESPC System Forecasts



- NAVGEM and ESPC do an acceptable forecasts of Patricia's path.
- The distance between NHC and ESPC path ranges from 15 to 137 km.

Current ocean models used at NCEP

- MOM4 in CFSv2 for S2S prediction (.25° to .5°), to be upgraded to MOM6 at .25° everywhere
- HYCOM uncoupled for short term prediction (1 to 10 days) initialized from Navy analysis (1/12° resolution) – soon in-house analysis using Navy NCODA (closed source)

Ideally, there should be one ocean model for seamless prediction => how should the global ocean component of UFS evolve?

HYCOM and MOM6 have very similar architectures

- Both use generalized vertical coordinates in the vertical using the Arbitrary Lagrangian-Eulerian (ALE) method
- Both use a C-grid tripolar grid in the horizontal

- But the MOM# models have traditionally been developed and used for seasonal/climate applications at coarse resolution (notable exception: BlueLink in Australia)
- While most HYCOM applications have been for high resolution Navy and NOAA/NCEP applications – latest at 1/50° (Chassignet and Xu, 2017)

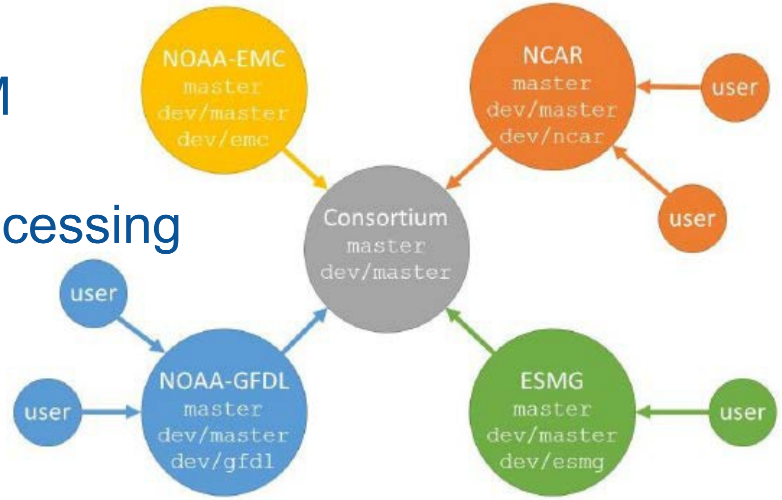
HYCOM 1/50° (Chassignet and Xu, 2017)

Features shared by HYCOM and MOM6

- C-grid rectangular cells, 2nd order finite volume
  - No demonstrated advantage to alternatives for global ocean models
- Supports a tri-pole global grid
  - Most common structured global curvilinear grid
  - Logically a single 2-D array with poles over land
- Arbitrary Lagrangian/Eulerian (ALE) in the vertical
  - Solve the layer continuity equation, then remap
  - Can "emulate" many other coordinate systems
- Split-explicit time step (mode splitting)
  - Short barotropic steps, to handle external gravity waves
  - MOM6 can in addition sub-cycle the baroclinic dynamics
- Bit for bit reproducibility on any number of cores
  - Global sums require care:
    - HYCOM uses 13x13 partial sums and then a fixed sum order
    - MOM6 calculates sums with fixed point arithmetic
- Active community of users

HYCOM/MOM6 collaboration

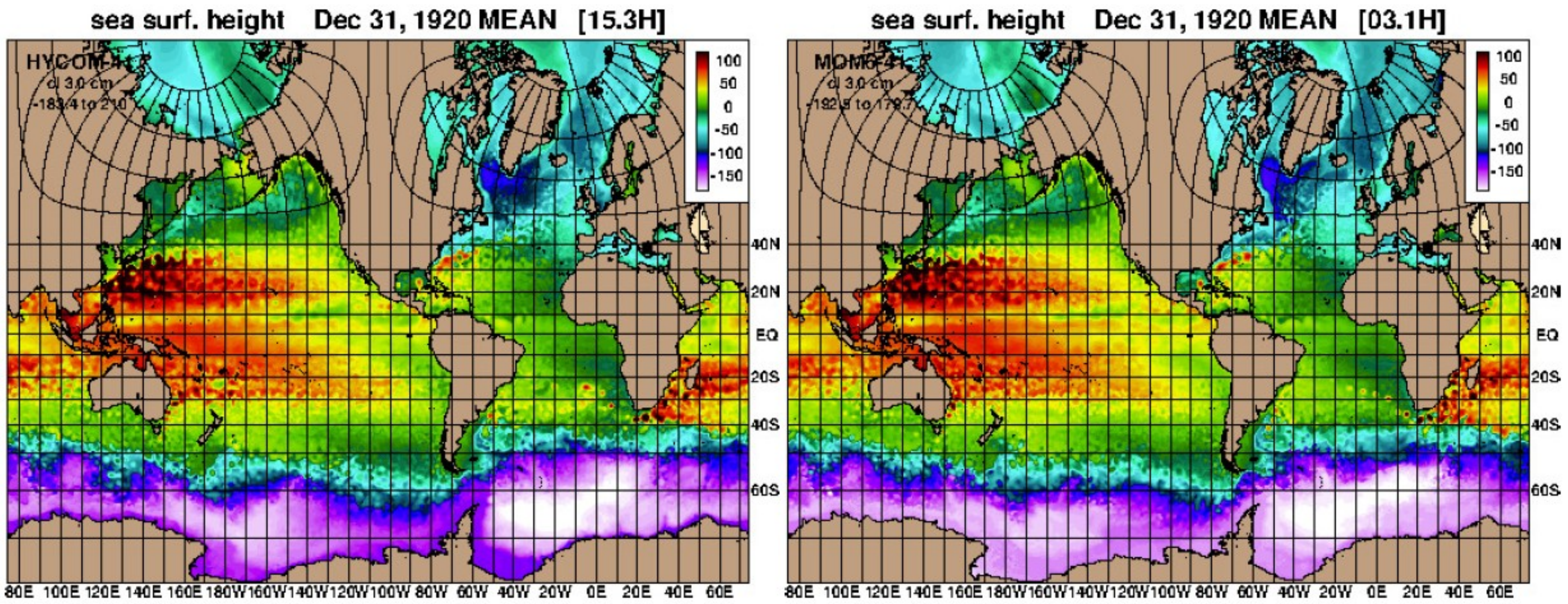
- HYCOM was the first widely used ALE-based ocean model
  - Demonstrated the viability of this approach
- HYCOM is no longer the only ALE-based ocean model
  - The new MOM6, in particular, has some advantages over HYCOM
- This led to exchanges between GFDL and FSU HYCOM developers
  - Navy and NOAA ESPC projects are funding exploratory development of HYCOM 3.0 in the HYMOM consortium, where GFDL becomes one of several major forks with master and dev/master hosted by the consortium
  - The HYCOM consortium becomes a major fork of the HYMOM consortium with MOM6 as the ocean model component - the fork is much more than an ocean model (pre- and post-processing standalone programs, scripts and a run environment for prescribed atmosphere cases, ocean-ice data assimilative cases and ESPC data assimilative cases)



Preliminary Steps Toward a National Ocean Modeling Capability in Support of the National Earth System Prediction Capability

MOM6 vs HYCOM on 0.08 degree Global Tripole Grid
Sea surface height (cm) after 10 model years

HYCOM **MOM6**

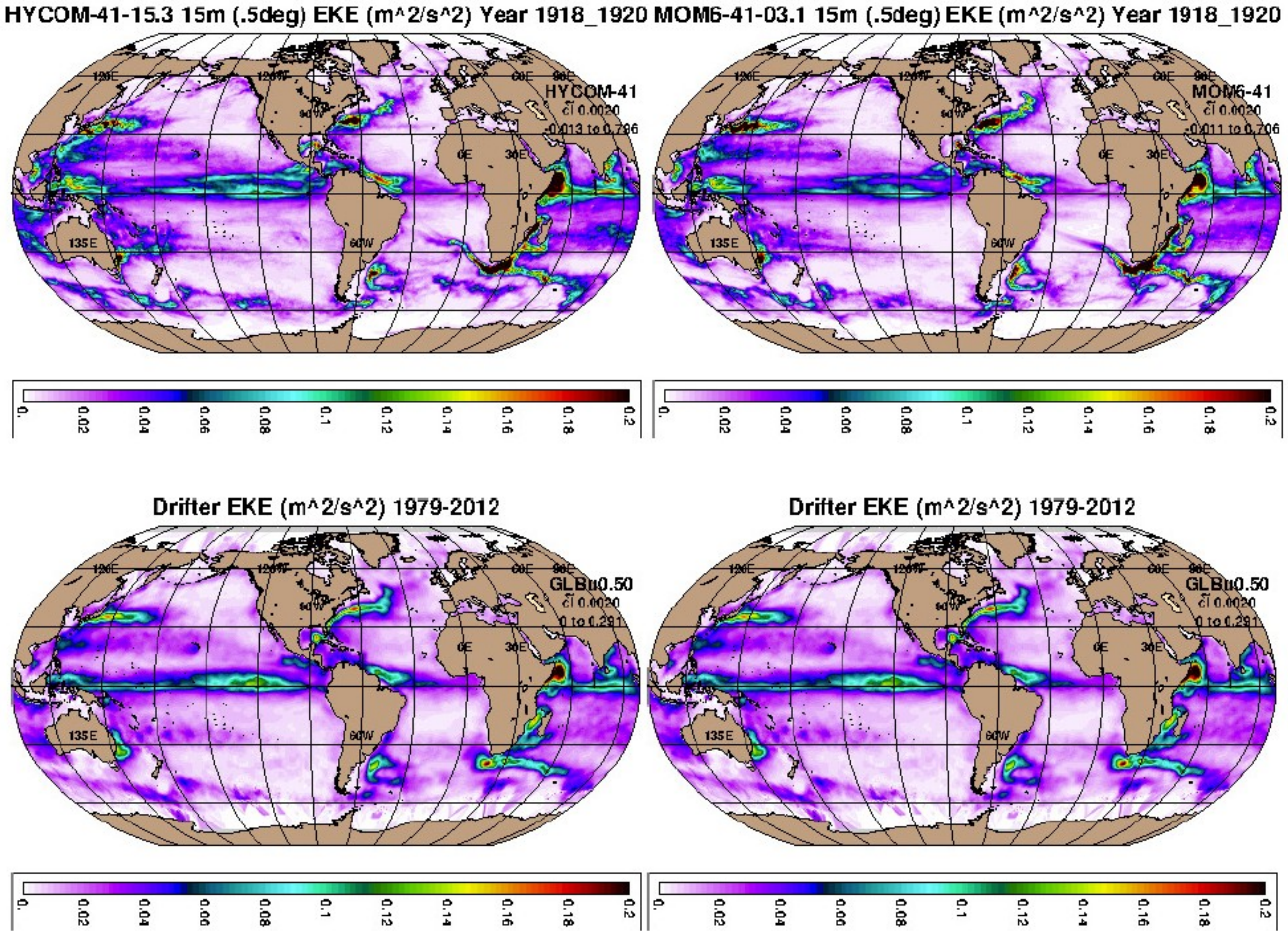


Very similar results.
MOM6 is about 1.6x faster, due to a longer time step, and does not have the thermobaric instabilities that can occur with HYCOM.

Eddy Kinetic Energy from Currents at 15 m

HYCOM (3 years)

MOM6 (3 years)



DRIFTERS (1979-2012)

Moving forward, adding features to HYMOM present in HYCOM, but not in MOM6

- Exactly mass conserving – a non-Boussinesq version of MOM6 exists, but not fully tested
- 4th order advection schemes
- Spatially varying target layer densities for vertical remapping
- Z-sigma-Z “fixed” coordinate near the surface
- Robust support for tides
- Incremental insertion of innovation fields (e.g., from 3DVAR)
- Etc.

Developing an UFS community high resolution global ocean prediction capability

- Open source ocean model (HYMOM) based on MOM6 => development underway – Navy not fully committed to HYCOM 3.0
- Missing piece is open source data assimilation. There is JEDI, with MOM6 applications under development – it however needs to be implemented and tested for high resolution eddy-resolving configurations, especially the projection of altimetry in ocean interior.
  - This is an essential component as global ocean forecasting relies almost exclusively on altimetry
  - The Navy uses synthetic profiles, but its package is closed source. There are alternative projection methods.
- Evaluation against current state-of-the-art HYCOM GOFS
- Seamless connection to coastal ocean prediction systems – can MOM6 be adapted to the coastal environment to minimize the number of nests?

Forecasting framework

- For the community to be involved in improving forecasts, a framework is needed
  - Access to
    - open-source ocean and data-assimilation codes
    - configurations
    - computer resources (a centralized location would facilitate this)
  - Provision of test configurations that can be modified and tested against clear metrics
  - Personnel to interact with users and maintain/update codes and configurations
- The framework will facilitate the integration of model components (e.g., the ocean) and further EPIC's goal of Earth Prediction

Thank you